

R & D WORK ON THE CONSTRAINED VAPOR BUBBLE SYSTEM
FOR A MICROGRAVITY EXPERIMENT

MONTHLY REPORT FOR NNC05GA27G

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This grant started on April 05, 2005. It is a continuation of NASA NAG3-2383. Published materials for NASA NAG3-2383 are listed in the final report for NAG3-2383. We have adopted a procedure for our monthly reports in that we will submit the Abstract and Conclusions from documents mailed out during the month. Abstract and Conclusions from SU 01, SU 02, SU 03 (original and revised), SU 04, SU 05, SU 06, SU 07, SU 08, SU 09, SU-10, SU-11, SU-12, SU 13, SU 15, PR01, PR02, PR03, IR 1, IR 2, IR 3, IR 4, IR 5, IR 6, & IR 7 by separate e-mail were previously reported. Complete copies of the published material are available upon request.

CURRENT MONTH:

- 1) The following Abstract was submitted: SU 16) “The Constrained Vapor Bubble Experiment for ISS-Earth’s Gravity Results” Arya Chatterjee, Joel L. Plawsky and Peter C. Wayner, Jr., David Chao, Ronald J. Sicker, Tibor Lorik, Louis Chestney, John Eustace, John Zoldak, Abstract Submitted to AIChE Annual Meeting, Nov, 2009. The Abstract is given below.
- 2) Since the Launch Date (August, 2009) is quickly approaching, there has been a significant increase in the emphasis of our work on the pre-flight data measurements at Zin-Tech and analyses thereof. Weekly telephone conferences are being held every Thursday with NASA and Zin-Tech to discuss progress, as we get closer to our launch date and the pre-flight review. Work is being done on the cuvettes with ethanol and those with Pentane.
- 3) We are working on building, testing and using the equipment for the experimental studies concerning the mixture and pure fluid in the loop configuration of the CVB at RPI. We are recording data concerning oscillations in the contact line region.
- 4) We are preparing a couple of papers for publication.

ABSTRACT FOR SU 16.

The constrained vapor bubble (CVB) experiment is one of the significant investigations into fluid physics in microgravity conditions being undertaken by NASA. Destined to fly on the International Space Station by the end of 2009, the experiment will yield data that will provide new insight into the complex phenomena occurring in systems such as nucleate boiling and heat pipes. It will consist of a transparent heat pipe made from quartz using pentane as working fluid with an extraordinary level of instrumentation allowing us, for the first time, to study every aspect of the heat pipe in great detail. Earth’s gravity based data was collected at NASA Glenn using an identical hardware to that from the ISS. This data will be compared with the space based data to better understand how the interfacial forces are affected in the microgravity environment where the Bond number will be very small. Here we present earth’s gravity environment data and try to match it with predictions from a theoretical model. The model uses the Young-Laplace equation to calculate the fluid pressure gradient and solves the momentum equation in the liquid and vapor phases. It also takes into account the heat conduction in the solid quartz and calculates the temperature profile along the heat pipe device which can be matched with the experimental data. Predictions will also be made about how the heat pipe device is expected to behave in space.

PAPERS/PRESENTATIONS (CURRENT STATUS)

PRESENTATIONS [PR]:

PR 01) Presented at 2005 Annual AIChE Meeting (Cincinnati, OH, Oct 30 – Nov. 4)
AIChE Paper #22828 : Sashidhar S. Panchamgam, Joel L. Plawsky and Peter C. Wayner, Jr.
“Spreading Characteristics and Microscale Evaporative Heat Transfer in a Moving Meniscus Containing a Binary Mixture” Extended Abstract submitted 9-02-05.

PR02) Presented at 2005 Annual AIChE Meeting (Cincinnati, OH, Oct 30 – Nov. 4)
AIChE Paper #23015 : Sashidhar S. Panchamgam, Joel L. Plawsky and Peter C. Wayner, Jr. “Microscale Heat Transfer and Fluid Flow in an Evaporating Moving Extended Meniscus” Extended Abstract submitted 9-02-05.

PR 03) (previously SU 01) Sashidhar S. Panchamgam, Joel L. Plawsky, and Peter C. Wayner, Jr., “Microscale Heat Transfer in an Evaporating Moving Extended Meniscus”, ECI Conference on Microscale Heat Transfer, Sept. 25-30, 2005, Castlevectchio Pascoli (Tuscany) Italy.

PR 04) Sashidhar S. Panchamgam, Joel L. Plawsky, and Peter C. Wayner, Jr., “Reflectivity Based Analysis of Contact Line Behavior and Microscale Heat Transfer in Ultrathin Films,” Poster at the 2nd Annual Tech Valley Engineering Symposium, April 18, 2006, Albany, NY.

PR 05) (previously SU 04) Presented at 9th Joint AIAA/ASME Thermophysics and Heat Transfer Conference, San Francisco, CA June 5-8, 2006: Sashidhar S. Panchamgam, Joel L. Plawsky, and Peter C. Wayner, Jr., “Influence of Marangoni Stresses and Slip on Spreading Characteristics of an Evaporating Binary Mixture Meniscus.”

PR 06) (previously SU 05) Presented at 4th International Conference of Nanochannels, Microchannels and Minichannels, June 19-21, 2006, Stokes Research Institute-University of Limerick, Limerick, Ireland: Sashidhar S. Panchamgam, Joel L. Plawsky, and Peter C. Wayner, Jr., “Experimental Evaluation of Marangoni Shear in the Contact Line Region of an Evaporating 99 + % Pure Octane Meniscus.”

PR 07) (previously SU 06) Sashidhar S. Panchamgam, Joel L. Plawsky, and Peter C. Wayner, Jr., “Reflectivity Based Analysis of Contact Line Behavior and Microscale Heat Transfer in Binary Ultrathin Films,” AIChE 2006 Annual Meeting, November 12-17, 2006, San Francisco, California.

PR 08) (previously SU 07) Peter C. Wayner, Jr., “Effects of Interfacial Phenomena and Conduction on an Evaporating Meniscus,” ICNMM2007-30021 Presented at (and published in the Proceedings of) Fifth International Conference on Nanochannels, Microchannels and Minichannels, June 18-20, 2007. Universidad De Las Americas Puebla, Mexico.

PR 09) Presented as Paper 304b (previously SU 09) Arya Chatterjee, Joel L. Plawsky and Peter C. Wayner, Jr., “A Multiscale Model For The Constrained Vapor Bubble Heat Pipe” presented at 2007 Annual AIChE Meeting, November 4-9, Salt Lake City, Utah.

PR 10) (Previously SU 10) Paper # 2008-0818. 22nd Symposium on Gravity-Related Phenomena in Space Exploration, January 7-10, 2008, Reno, NV. “R&D Work on the Constrained Vapor Bubble System for a Microgravity Experiment”, Arya Chatterjee, Joel L. Plawsky and Peter C. Wayner, Jr.

PR11) Arya Chatterjee, Joel L. Plawsky and Peter C. Wayner, Jr. “ Continuum Models with Slip for the Evaporating Meniscus and Comparison with Experimental Results” Paper Number: ICNMM2008-62080 Sixth International Conference on Nanochannels, Microchannels and Minichannels,” TU Darmstadt, Germany, June 23-25, 2008.

PR12) Keynote Presentation: Peter C. Wayner, Jr., “Thermal-Physical-Chemical Phenomena in the Contact Line Region”, The Third International Topical Team Workshop on Two-Phase Systems for Ground and Space Applications in Brussels, Belgium during September 10-12, 2008. This was partly sponsored by the European Space Agency that is expanding their micro-gravity program on the ISS.

PR13) (Previously SU 12) Arya Chatterjee, Joel L. Plawsky and Peter C. Wayner, Jr. "Oscillations In An Evaporating Meniscus" ID#: 126554, Presented in Engineering Sciences and Fundamentals Session, 2008 Annual Meeting of AIChE, November 16-21, 2008 Philadelphia, PA.

PR14) Presentation at International Space Station (ISS) Increment 19 Science Symposium on March 4, 2009.

PUBLICATIONS [PU]:

PU 01) (previously SU 02 and originally SU 16 under NAG 3-2383) S. J. Gokhale, J. L. Plawsky, and P. C. Wayner, Jr. , “Spreading, Evaporation, and Contact Line Dynamics of Surfactant Laden Micro-Drops” *Langmuir*, Vol. 21, pp 8188-8197, No. 18, Sept. 2005.

PU 02 (previously SU 01) Sashidhar S. Panchamgam, Joel L. Plawsky, and Peter C. Wayner, Jr. ,”Microscale Heat Transfer in an Evaporating Moving Extended Meniscus”, *Experimental Thermal and Fluid Sciences*, Vol. 30, pp 745-754 (2006), [Preliminary version in Proceedings of ECI Conference on Microscale Heat Transfer, Sept. 25-30, 2005, Castlevectchio Pascoli (Tuscany) Italy].

PU 03) (previously SU 04) Sashidhar S. Panchamgam, Joel L. Plawsky, and Peter C. Wayner, Jr. , “Influence of Marangoni Stresses and Slip on Spreading Characteristics of an Evaporating Binary Mixture Meniscus” Proceedings of the 9th Joint AIAA/ASME Thermophysics and Heat Transfer Conference, San Francisco, CA June 5-8, 2006.

PU 04) (previously SU 05) Sashidhar S. Panchamgam, Joel L. Plawsky, and Peter C. Wayner, Jr. , “Experimental Evaluation of Marangoni Shear in the Contact Line Region of an Evaporating 99 + % Pure Octane Meniscus” ICNMM2006-96060, Proceedins of 4th International Conference of Nanochannels, Microchannels and Minichannels, June 19-21, 2006, Stokes Research Institute-University of Limerick, Limerick, Ireland.

PU 05) (previously SU 03) Sashidhar S. Panchamgam, Joel L. Plawsky, and Peter C. Wayner, Jr., “Spreading Characteristics and Microscale Evaporative Heat Transfer in an Ultra-Thin Film Containing a Binary Mixture,” *ASME Journal of Heat Transfer*, 2006, **128**, pp. 1266- 1275.

PU 06) (previously SU 07) Peter C. Wayner, Jr., “Effects of Interfacial Phenomena and Conduction on an Evaporating Meniscus,” ICNMM2007-30021 Presented at (and published in the Proceedings of) Fifth International Conference on Nanochannels, Microchannels and Minichannels, June 18-20, 2007. Universidad De Las Americas Puebla, Mexico.

PU 07) Sashidhar S. Panchamgam, Joel L. Plawsky, and Peter C. Wayner, Jr. , “Experimental Evaluation of Marangoni Shear in the Contact Line Region of an Evaporating 99 + % Pure Octane Meniscus.” *ASME Journal of Heat Transfer*, **129**, pp. 1476-1485, 2007. (Expanded version of PR 06)

PU 08) (Previously SU 10) Paper # 2008-0818. Proceedings of the 22nd Symposium on Gravity-Related Phenomena in Space Exploration, January 7-10, 2008, Reno, NV. “R&D Work on the Constrained Vapor Bubble System for a Microgravity Experiment”, Arya Chatterjee, Joel L. Plawsky and Peter C. Wayner, Jr.

PU-09) Arya Chatterjee, Joel L. Plawsky and Peter C. Wayner, Jr. “ Continuum Models with Slip for the Evaporating Meniscus and Comparison with Experimental Results” Paper Number: ICNMM2008-62080 Sixth International Conference on Nanochannels, Microchannels and Minichannels,” TU Darmstadt, Germany, June 23-25, 2008. (Previously (SU 11).

PU-10) Sashidhar S. Panchamgam, Arya Chatterjee, Joel L. Plawsky, and Peter C. Wayner, Jr. , “Comprehensive experimental and theoretical study of fluid flow and heat transfer in a microscopic evaporating meniscus in a miniature heat exchanger.” *International Journal of Heat and Mass Transfer*, **51**, pp. 5368-5379, 2008.

PU-11) The following paper is now available online at Chemical Engineering Communications: “Review of the Effects of Surface Topography, Surface Chemistry, and Fluid Physics on Evaporation at the Contact Line”, Plawsky, Joel; Ojha, Manas; Chatterjee, Arya, and Wayner, Jr. Peter C. ,*Chemical Engineering Communications* 196, no. 5 (2009): 658-696.

SUBMITTED/ ACCEPTED [SU]:

SU 01) Moved to PU 02 and PR 03.

SU 02) Moved to PU 01

SU 03) Moved to PU 05.

SU 04) Moved to PU 03.

SU 05) Moved to PU 04 and PR 06.

SU 06) Moved to PR 07.

SU 07) Moved to PR 08.

(SU 08) Moved to PU 10)

(SU 09) Moved to PR 09.

(SU 10) Moved to PR 10 and PU 08.

(SU 11) Moved to PR 11..

(SU 12) Moved to PR 13.

(SU 13) Arya Chatterjee, Joel L. Plawsky and Peter C. Wayner, Jr. “ Oscillating Evaporating Meniscus” Paper for 8th World Congress of Chemical Engineering. August 23-27, 2009, Montreal, Canada.

SU 14) Moved to PR 14.

SU 15) “The Role of Solid Surface Structure on Dropwise Phase Change Processes” , Manas Ojha, Arya Chatterjee, Frank Mont, E F Schubert , Peter C. Wayner Jr., Joel L. Plawsky, Submitted to International Journal of Heat and Mass Transfer.

SU 16) “The Constrained Vapor Bubble Experiment for ISS- Earth’s Gravity Results” Arya Chatterjee, Joel L. Plawsky and Peter C. Wayner, Jr., David Chao, Ronald J. Sicker, Tibor Lorik, Louis Chestney, John Eustace, John Zoldak, Abstract Submitted to AIChE Annual Meeting, Nov, 2009.

PROPOSED, AND IN PREPARATION [PRE]:

THESES [T], RELATED STUDENT PROPOSALS [PRO], AND INTERNAL REPORTS [IR]

PRO 1) Sashidhar S. Panchamgam, ”Study of Microscale Transport Processes and Interfacial Phenomena in Evaporating Thin Films Using Vertical Constrained Vapor Bubble (VVCB)”, Ph. D. Dissertation Proposal, Isermann Department of Chemical and Biological Engineering, Rensselaer Polytechnic Institute, Troy, NY, May, 2005.

T 1) Sashidhar S. Panchamgam, ”Interfacial Phenomena and Microscale Transport Processes in Evaporating Ultrathin Menisci” Ph. D. Thesis, The Isermann Department of Chemical and Biological Engineering, Rensselaer Polytechnic Institute, Troy, NY, September, 2006.

IR 1) Arya Chatterjee and Peter C. Wayner, Jr., Report on tour to the flight hardware for CVB 6-9 August, 2007, Zin Tech, North Olmsted, OH

IR 2) Professor Plawsky and Wayner along with GA Arya Chatterjee visited NASA and Zin-Tech during the week of December 3 to discuss the progress being made on the ISS experiment. The report (IR 2) on the visit is given in the January 1, 2008 Monthly Report.

IR 3) Professor Plawsky and Wayner along with GA Arya Chatterjee visited NASA and Zin-Tech during the week of 31 March - 4 April to discuss the flight hardware. The report (IR 3) on the visit is given in the May 1, 2008 Monthly Report.

IR 4) Arya Chatterjee, Discussion of problems with filling cuvette at Zin-Tech sent as an attachment to e-mail to the group on October 6, 2008 from Arya Chatterjee.

IR 5) IR 4) Arya Chatterjee, Suggested solution of problems with filling cuvette at Zin-Tech sent as an attachment to e-mail to the group on October 6, 2008 from Arya Chatterjee.

IR 6) December 15, 2008 e-mail : Arya Chatterjee, Joel L. Plawsky and Peter C. Wayner, Jr. "CVB Module Fill Acceptability" .

IR 7) A proposed draft of the Test Matrix was submitted as an attachment to an e-mail from Arya Chatterjee on Nov. 19, 2008.

IR 8) draft of EDMP, Experimental Data Management Plan, sent as attachment to e-mail from Joel Plawsky on January 30, 2009.

IR 9) Arya Chatterjee, "The Constrained Vapor Bubble-On Earth and In Space", Doctoral Candidacy Proposal, February, 2009.

ANNUAL PROGRESS REPORTS [ANN]:

ANN 1) Peter C. Wayner, Jr and Joel L. Plawsky, "R & D Work on the Constrained Vapor Bubble System for a Microgravity Experiment: First Annual Progress Report for NNC05GA27G for the Period April 5, 2005 –February 4, 2006" submitted February, 2006.

ANN 2) Peter C. Wayner, Jr and Joel L. Plawsky, "R & D Work on the Constrained Vapor Bubble System for a Microgravity Experiment: Second Annual Progress Report for NNC05GA27G for the Period April 5, 2006 –February 4, 2007" submitted February, 2007.

ANN 3) Peter C. Wayner, Jr and Joel L. Plawsky, "R & D Work on the Constrained Vapor Bubble System for a Microgravity Experiment: Third Annual Progress Report for NNC05GA27G for the Period April 5, 2007 –April 4, 2008" submitted February, 2008.

ANN 4) Peter C. Wayner, Jr and Joel L. Plawsky, "R & D Work on the Constrained Vapor Bubble System for a Microgravity Experiment: Fourth Annual Progress Report for NNC05GA27G for the Period April 5, 2008 –April 4, 2009" submitted February, 2009.